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AUTHOR(S):

MITSUTA, Yasushi

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A NEW REDUCTION METHOD OF ANEMOMETER-BIVANE DATA

By

Yasushi MITSUTA

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Abstract

A new reduction method of anemometer-bivane data is proposed. By this new digital reduction method fine structure of vertical wind fluctuations can be visualized free from dynamic response character of the particular bivane, which tends to exaggerate fluctuations in the same period as free period of the bivane. This method was tested by the comparative field observation with a sonic anemometer. The result was proved to be satisfactory.

1. Introduction

Anemometer-bivane method for determination of vertical wind velocity component is one of the widely used techniques in the study of atmospheric turbulence. This method is more practical in field measurement than other methods such as hot-wire method. But the dynamic response character of the bivane is much worse than hot-wire that is caused by large inertia of the vane and small aerodynamic damping force on the vane. This is the fundamental limitation in applying this method.

Brock [1963] has made a multi-channel machine reduction system for anemometer-bivane, but he did not care in this point. While MacCready [1964] has proposed to use the bivane which has optimum dynamic character for the particular purpose of the observation. However, it is extremely difficult to design the bivane which has desirable characteristics. In this paper a new data reducing method to correct the dynamic character of the bivane is proposed. This method is applicable to any kind of wind vane.

2. New Reducing Method

The equation of motion of a wind vane in changing wind is shown as follows (Sanuki (1953))

$$-\frac{d^2\beta}{dt^2} + 2\zeta\left(\frac{2\pi}{T_0}\right)\frac{d\beta}{dt} + \left(\frac{2\pi}{T_0}\right)^2\beta = \left(\frac{2\pi}{T_0}\right)^2\alpha, \quad (1)$$

where β is the angular position of the vane, α wind direction, ξ logarithmic damping ratio of the vane and T_0 period of free oscillation in steady wind. Two parameters involved are studied by Sanuki and it is concluded that ξ is not affected by wind speed and T_0 is inversely proportional to it. Thus T_0 is shown as

$$T_0 = L/V, \quad (2)$$

where L is characteristic length of the vane and V wind speed.

Eq. 1 has the same form as a second order response function in electronics and the solution is studied in detail already. The parameters can be easily determined from transient response character of the vane in the wind tunnel test (Sanuki [1953]).

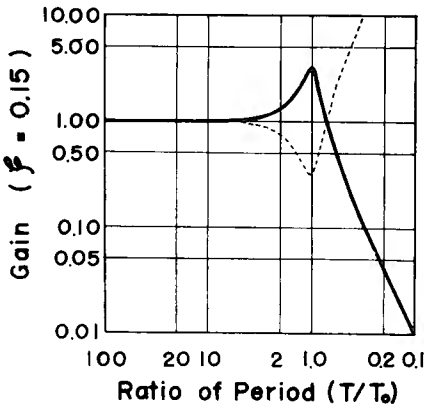


Fig. 1. An example of frequency response character of a bivane.

While the anemometer has much better response character than the bivane in most cases and correction is not required.

It is not so easy to correct this distortion by electric circuits in analogue form because the free oscillation period, T_0 changes with wind speed. So the new reduction method was intended to apply in the course of digital data processing procedure.

Eq. 1 can be rewritten as follows

$$\alpha = \beta + \frac{\xi T_0}{\pi} \frac{d\beta}{dt} + \frac{T_0^2}{4\pi^2} \frac{d^2\beta}{dt^2}, \quad (3)$$

and using the relation of Eq. 2

$$\alpha = \beta + \left(\frac{\xi L}{\pi V} \right) \frac{d\beta}{dt} + \left(\frac{L^2}{4\pi^2 V^2} \right) \frac{d^2\beta}{dt^2}. \quad (4)$$

Vertical velocity component, W can be approximated by $V\alpha$. Using Eq. 4, it becomes

In case of short period wind fluctuations, which has period in the same order of T_0 or less, the first and second terms become too large to ignore compared to the last term in the left hand side of Eq. 1. As the wind vane of normal dimension has characteristic length of about one to ten meters, the frequency range, which is most interested in the study of atmospheric turbulence, is distorted in most cases. Fig. 1 shows an example of frequency response of a bivane.

$$W = V\beta + \left(-\frac{\xi L}{\pi}\right) \frac{d\beta}{dt} + \left(-\frac{L^2}{4\pi^2 V}\right) \frac{d^2\beta}{dt^2}. \quad (5)$$

Only the first term of the right hand side alone has been used in traditional vertical velocity estimate and the last two terms are new correction terms. In case of wind measurement near the ground these correction terms are often as large as the first term in magnitude.

In the practical reduction process of discrete samples, the above equation can be rewritten as

$$W_0 = V_0\beta_0 + \frac{\xi L}{2\pi Dt}(\beta_{+1} - \beta_{-1}) + \frac{L}{4\pi^2 V_0(Dt)^2}(\beta_{+1} + \beta_{-1} - 2\beta_0), \quad (6)$$

Where $+1$ and -1 suffixes mean the values of the variables at Dt seconds after and before 0 time. As we can measure wind speed, V by the anemometer and inclination, β by the bivane, the true vertical velocity, W is obtained by applying this correction. But to have satisfactory results we should sample the data in much shorter period than free period of the vane, that is, Dt should be much less than T_0 .

3. Example

This method was tested by the data of the bivane observation at the Shionomisaki Wind Effect Laboratory of Kyoto University. The characteristic length of the bivane is 15 meters and damping ratio being 0.15 (Mitsuta [1964]). The frequency response character is shown in Fig. 1. The anemometer used with it is an ordinal aerovane type anemometer.

The observation was made at the top of the wind tower of 10 meters in height. The anemometer, bivane and standard sonic anemometer (Mitsuta [1966]) were placed in every 2 meters. An example of traces of the sonic anemometer and bivane is shown in Fig. 2. Even the rough shape of the traces are almost similar each other, but it can be seen that the fluctuations in free period are exaggerated in the bivane trace.

The data were sampled for 3 minutes in duration and 0.5 seconds in interval.

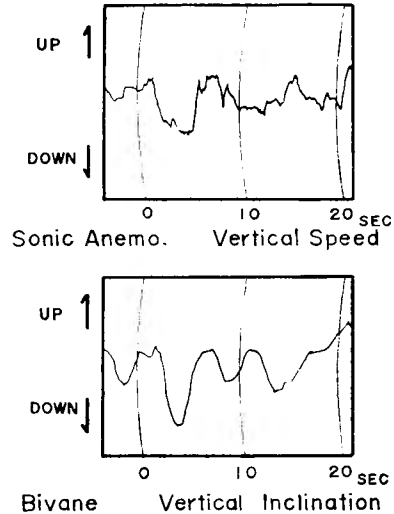


Fig. 2. An example of simultaneous traces of sonic anemometer and bivane inclination of the comparative observation at Shionomisaki on Sept. 9, 1963.

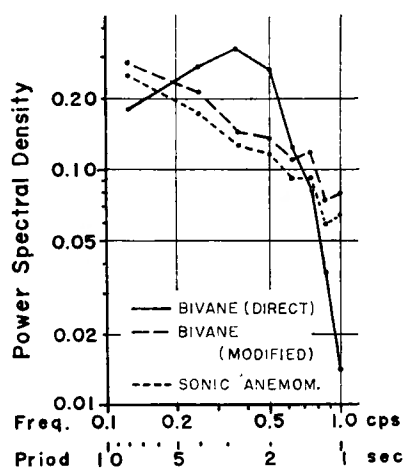


Fig. 3. Power spectra (in arbitrary unit) of three kinds of vertical wind component estimates.

Vertical wind components were computed by the traditional and new method, and compared with the sonic anemometer trace. This sampling interval corresponds to about one sixth of the free period of the bivane in this case in which the mean wind speed was 5.3m/sec and free period being about 3 sec.

The power spectra of three kinds of vertical wind speed estimates are shown in Fig. 3. An energy peak is seen on the spectrum of the data by the traditional method using only the first term of Eq. 6 at the period of about 3 seconds, which corresponds to the free period (Eq. 2).

This peak and sharp cut off adjacent to it are apparently fictitious caused by low fidelity of the bivane and are not seen on the spectrum obtained from sonic anemometer data (in dotted line). But this peak disappears on the modified bivane data using full terms of Eq. 6 (in broken line) and it is very much like the sonic spectrum. This means that the reduction process was proper one.

4. Conclusion

As is clear from the example the new reduction method is effective in removing the effect of dynamic response character of the bivane in processing anemometer-bivane data. This method is quite easy and does not require much time in machine reduction of the data in digital form.

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